

# Kepler's Search: Are There Habitable Planets Beyond Our Solar System?

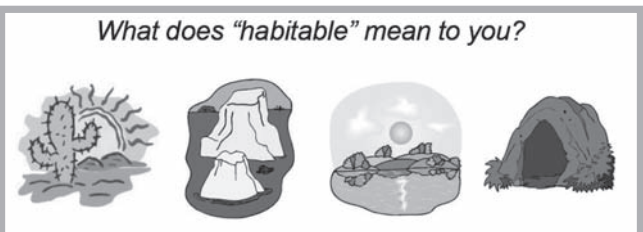
by Dr. David Koch, Deputy Principal Investigator, *Kepler Mission*

Is Earth unique in the universe? How abundant are habitable planets? What constitutes being habitable? NASA's *Kepler Mission* team seeks to answer these questions. The *Kepler Mission* spacecraft, (*Kepler*) launching in 2009, is NASA's first mission capable of finding Earth-size and smaller planets in the habitable zone of other stars in our neighborhood of the Milky Way Galaxy. For the first time in human history, we will know if there are planets capable of supporting life beyond our solar system.

## Planets Vary Widely

- What are the differences among the planets in our solar system?
- How do their sizes compare? their masses? their temperatures? their surfaces?
- Why would one of the planets be more or less habitable than another?
- How is Earth uniquely different from all the others?

If you could create a planet where you would be able to survive, what would be the important features of the planet?



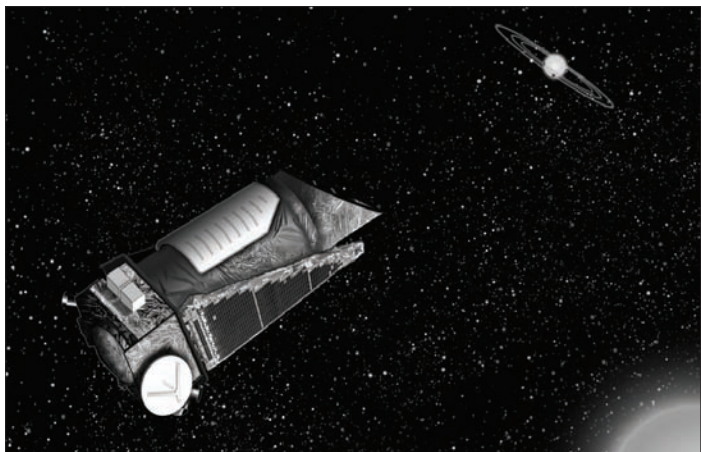
Note: We are not talking about whether there are burger joints, TVs, iPods or other technological conveniences. We are talking about the basic requirements for life as we know it.

Two fundamental characteristics for a habitable planet stand out:

1. The first is the temperature of the planet: What happens to water on the surface of a planet if the planet is too close to its star? Or too far away from its star? What does this tell you about the orbit of a planet?

2. The second is the mass or size of the planet: What must the size or mass of a planet be for it to have a life-sustaining atmosphere? Consider the following: If the mass is too small, then there is not enough gravity to hold onto an atmosphere. The Moon, Mercury and Mars are all too small to have a life-sustaining atmosphere. On the other hand, if the mass of a planet reaches about ten times the mass of the Earth, it has enough surface gravity to hold onto the most abundant and lightest elements in the universe, hydrogen and helium, and grow into a gas giant, such as Jupiter or Saturn, Uranus or Neptune. There are many other important features of our Earth's atmosphere: it transports water, it protects us from the Sun's ultraviolet radiation and cosmic rays from space, it contains the oxygen we breathe, and acts like a blanket to keep us warm.

Page 1



As in Goldilocks, there is a "just-right" orbit around a star. We call it the habitable zone. And there is a "just-right" size or mass for a planet, between about half an Earth mass to about ten times an Earth mass. Based on these criteria, scientists designed the *Kepler Mission* to be capable of detecting Earth-size planets in the habitable zone of other stars.

## Hunting for Earth-size Planets Beyond Our Solar System

We certainly cannot send a spacecraft from star to star to find another Earth. The stars are too far away. And we cannot take a picture of a distant planet even with any of the new powerful telescopes, either from the ground or from space. The problem is that the direct light from a distant star is billions of times brighter than the tiny amount of light reflected from a planet. So we have to be innovative in doing our observing.

The method used by the *Kepler Mission* is to plan for the tiny change in brightness in a star that happens when a planet crosses in front of a star. If the orbit of the planet is aligned along our line of sight to the star we will see these passages, called transits, as the planet orbits its parent star. For an Earth-size planet, the change in brightness is very small, about 1 part in 12,000 (the ratio of the area of the planet to the area of the star). The transit lasts for about half a day. And it happens only once an orbit, that is, about once every Earth year, if the planet is in the habitable zone of a star like our Sun.

## Mission Design

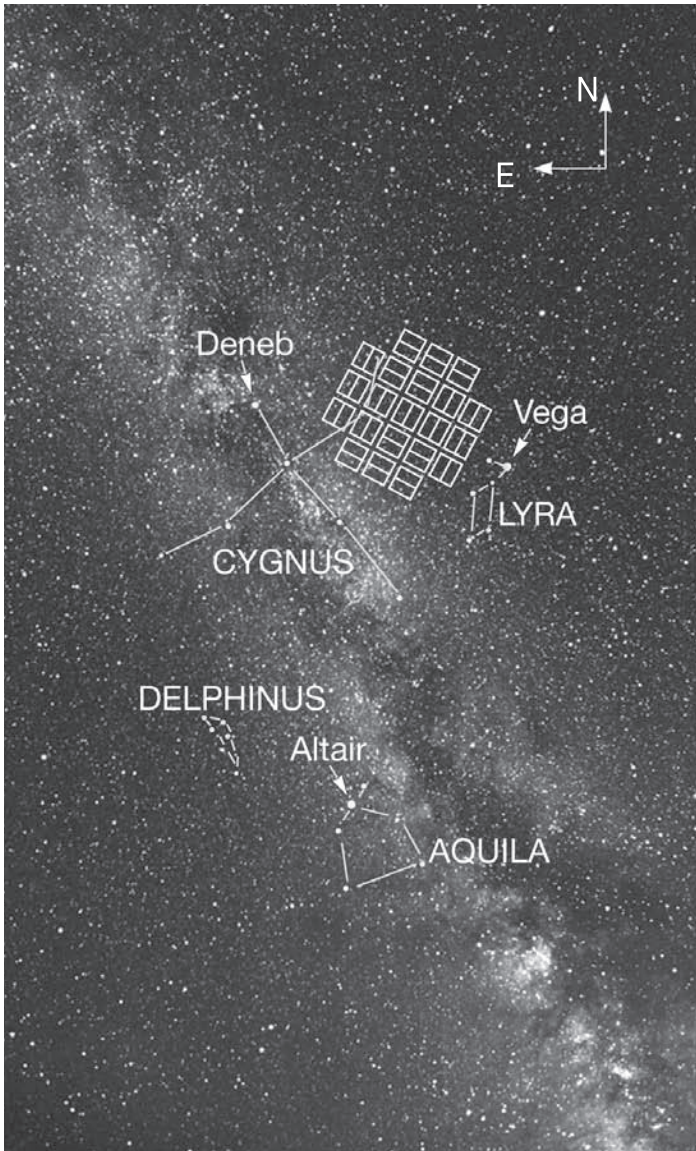
To make these observations, NASA scientists designed a special kind of telescope called a photometer; it's a highly sensitive light meter. It is dedicated to looking for planets as they transit stars. It will be pointed at just one large area in the sky and stare continuously for 3.5 or more years at about 100,000 stars that are similar to our Sun. The *Kepler* telescope has a very large field of view compared to typical astronomical telescopes.

To measure the light from many stars all at the same time, *Kepler* uses detectors called charge coupled devices (CCDs). These are similar to the CCDs found in commercial digital cameras. However, unlike a camera you can hold in your hand, with just a few million pixels

(megapixels), *Kepler's* CCD's have 95 megapixels. (Pixel is a term used to refer to the smallest picture element in a digital image.)

The field of view of *Kepler* is a bit larger than the size of your hand held out at arm's length. It is shown on the front of the poster and in the photograph below by all the little rectangles that represent the CCD's.

To conduct the search, *Kepler*, launching in 2009, is orbiting around the Sun, not the Earth, as shown on the front of the poster. The measurements from *Kepler* are radioed back to Earth where scientists analyze them to look for periodic sequences of transits, which are the signatures of planets orbiting other stars.



## Locating the Kepler Star Field

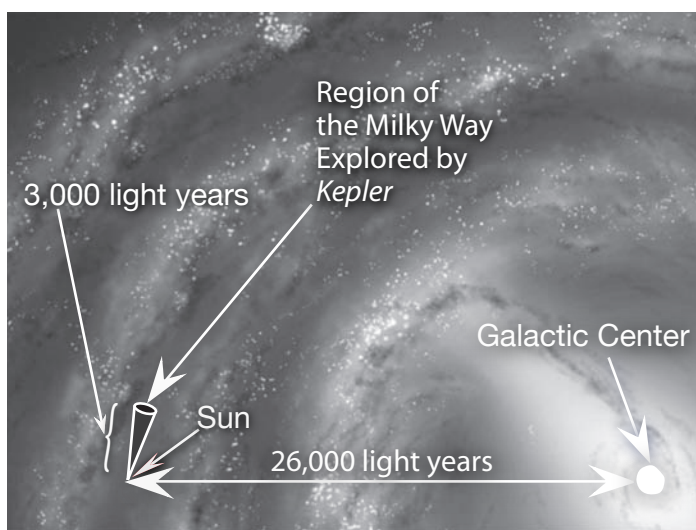
*Kepler's* star field is located in a portion of the Milky Way, shown in the photograph above as the diagonal band of stars, positioned between two of the brightest stars in the sky, Vega and Deneb. Vega and Deneb, along with Altair, form the summer triangle. The three stars of the summer triangle are part of the constellations Cygnus, the swan; Lyra, the harp; and Aquila, the eagle. The field is directly overhead at midnight in late July for mid-northern latitudes. The star

Page 2

field is about 15° across or bigger than your hand held out at arm's length. You can locate the *Kepler* star field on a star map and use a planisphere to determine when and where to look on the night sky. (<http://kepler.nasa.gov/ed/starwheel>)

## Distances to the Kepler Stars

The illustration below shows our understanding of the shape of our galaxy and the location of our Sun relative to the galactic center. The Sun is about 26,000 light years from the center of the galaxy, less than half the distance from the center to the edge. The cone shows the region of the Milky Way that *Kepler* searches. *Kepler* looks along a spiral arm of our galaxy. The distance to most of the stars for which Earth-size planets can be detected by *Kepler* is from about 600 to 3,000 light years. Fewer than 1% of the stars in the field of view are closer than 600 light years. Stars farther than 3,000 light years are too faint for *Kepler* to observe the transits needed to detect Earth-size planets.



## What We Expect to Discover

Three or more transits of a given star all with a consistent period, brightness change and duration provide a rigorous method of detection and confirmation. The data reveals the planet's:

- Size, from the brightness change and size of the star;
- Orbital period, from the time between transits;
- Orbital size, from the period, Kepler's Third Law, and the mass of the star;
- Temperature, from orbital size and temperature of the star.

From the data, scientists can calculate the fraction of stars that have planets and the distribution of planetary sizes and orbits for many different types of stars. The results will tell us how often planets occur in the habitable zone of other stars.

At the beginning of the mission, planets of all sizes orbiting very close to their stars will be found. After three years, planets will be discovered with orbits of one year in the habitable zone of stars like the Sun. If Earth-size planets in the habitable zone are common, then life may be ubiquitous in our galaxy. On the other hand, if no terrestrial planets are found, then "Earths" may be rare. Learn more at <http://kepler.nasa.gov>

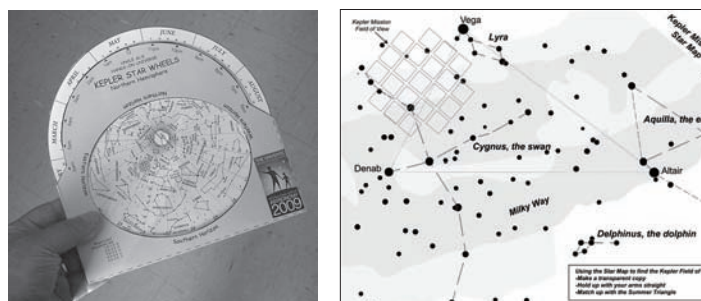
## How to Use This Poster

This poster illustrates the story of the NASA *Kepler Mission*. It shows the *Kepler* spacecraft's position in our solar system relative to the Earth, Sun and other planets. The *Kepler* spacecraft observes a portion of our Milky Way Galaxy to monitor stars for transits. The outlined squares show the area of the sky (field of view) that *Kepler* observes to search for transits over the life-time of the mission. Star maps of the *Kepler* field of view are available on the project website, <http://kepler.nasa.gov/ed/starwheel>

This side of the poster provides information about NASA's *Kepler Mission* and classroom-tested educational activities. The poster is designed so that each panel can be copied onto 8 1/2 inch by 11 inch paper on a standard copier. All of the panels that appear here are also available at the *Kepler Mission* website as PDF files that can be downloaded and printed. The panels are:

- **Kepler's Search: Are There Habitable Planets Beyond Our Solar System?** A 2-panel background article on the *Kepler Mission*. More detailed and extensive information is available at the *Kepler Mission* website: <http://kepler.nasa.gov>
- **How to Use This Poster:** General information, science education standards, credits, and further resources.
- **Detecting Extrasolar Planets:** Students construct and demonstrate transit models to learn about the search for extrasolar planets using the transit detection method.
- **Human Powered Orrery:** Students model the orbits of planets in the solar system in a kinesthetic activity.
- **Investigation: Transit Tracks:** Students learn about transits, how a planet's size and distance from its star affect the transit, and how to interpret light curves to deduce information about extrasolar planetary systems.

Additional materials that extend these lessons are available on the *Kepler Mission* website, such as the downloadable star maps below.



"Uncle Al's Star Wheel" for star gazing, and a star map for finding *Kepler's* field of view.

## Science Education Standards

**Detecting Extrasolar Planets and Human-Powered Orrery** support the following *National Science Education Standards (NSES)* National Academy Press, 1996, and *AAAS Benchmarks for Science Literacy (Benchmarks)* Oxford University Press 1993:

- **NSES Grades 5 – 8:** Content Standard D: Earth and Space Science: Earth in the Solar System: "Most objects in the solar system are in regular and predictable motion. Those motions explain such phenomena as the day, the year, phases of the moon, and eclipses."

- **NSES Grades 5 – 8:** Content Standard A: Science as Inquiry: Understandings About Scientific Inquiry: "Different kinds of investigations suggest different kinds of scientific investigations. Some investigations involve observing and describing objects, organisms or events; some involve collecting specimens; some involve experiments; some involve seeking more information: some involve discovery of new objects and phenomena; and some involve making models."
- **Benchmarks Grades 6 – 8:** The Earth: "We live on a relatively small planet, the third from the sun in the only system of planets definitely known to exist (although other similar solar systems may be discovered in the universe)."
- **Benchmarks Grades 6 – 8:** Models: "Different models can be used to represent the same thing...Choosing a useful model is one of the instances in which intuition and creativity come into play in science, mathematics, and engineering."

**Investigation: Transit Tracks** and the extension **Going Further – Optional Activities** support the following standards:

- **NSES Grades 9 – 12:** Content Standard A: Science as Inquiry: Understandings About Scientific Inquiry: "Scientists rely on technology to enhance the gathering and manipulation of data. New techniques and tools provide new evidence to guide inquiry and new methods to gather data, thereby contributing to the advance of science. The accuracy and precision of the data, and therefore the quality of the exploration, depends on the technology used."
- **NSES Grades 9 – 12:** Content Standard A: Science as Inquiry: Understandings About Scientific Inquiry: "Mathematics is essential in scientific inquiry. Mathematical tools and models guide and improve the posing of questions, gathering data, constructing explanations and communicating results."

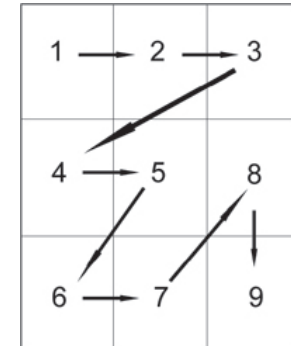
## Credits

The *Kepler Mission* Education and Public Outreach program is conducted for NASA by a team that includes Dr. David Koch, Deputy Principal Investigator for the *Kepler Mission*, Alan Gould of Lawrence Hall of Science, Edna DeVore and Pamela Harman of the SETI Institute, and Wendy Stenzel, *Kepler Mission* science communications and graphic design.

The Human Powered Orrery and Detecting Extrasolar Planets are adapted from the Great Explorations in Math and Science (GEMS) Space Science Sequence for grades 6-8. <http://hsgems.org/CurriculumSequences.htm>. Investigation: Transit Tracks is adapted from Full Option Science System (FOSS) Planetary Science course <http://www.fossweb.com/modules/MS/PlanetaryScience>. Both are from the Lawrence Hall of Science. © 2008 by the Regents of the University of California. May be reproduced for nonprofit educational use.

Page numbering on the poster follows the scheme in this diagram, to make best sense of the order of activities, each of which is two pages long.

The *Kepler Mission* poster can be downloaded at <http://kepler.nasa.gov>



Page 3

## Detecting Extrasolar Planets

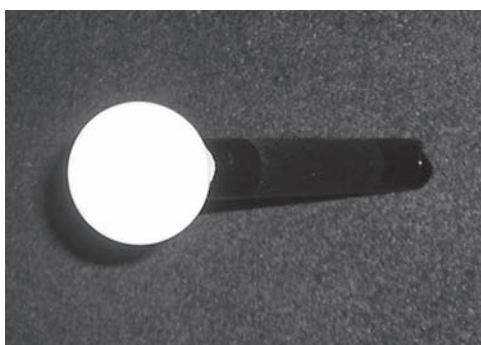
In this activity, students learn about the search for extrasolar planets using the method of transit detection. Teams construct models that demonstrate transits.

## Materials

**For the class**  
Download Earth-based image of Venus transit by Becky Lowder (to the right).

**For each team of 4-6 students — materials to make a model transit**

- 1 "model star" light-source, preferably a non-LED reading light or flashlight that can have a ping-pong ball (with a hole made in it) mounted over the light (see photo below). Alternatively, a plug-in lamp with frosted bulb, no lamp shade (e.g. portable goose-neck lamp, swing-arm lamp, or clamp-on lamp), and extension cords as needed.
- Several round, opaque beads — 5 mm to 15 mm in diameter
- 2-5 pipe cleaners — 30 cm (1 ft) long
- 1-2 chopsticks or thin dowels
- Black thread — about 1 m
- Index cards
- Tape
- Modeling clay
- Bag to hold the above materials
- Safety glasses for all students



- Unlike stars, planets don't generate their own light. Instead, they reflect the light coming to them from stars, and shine very dimly.
- Even viewed through a telescope, the light from a planet is overwhelmed by the light from the star that it orbits.

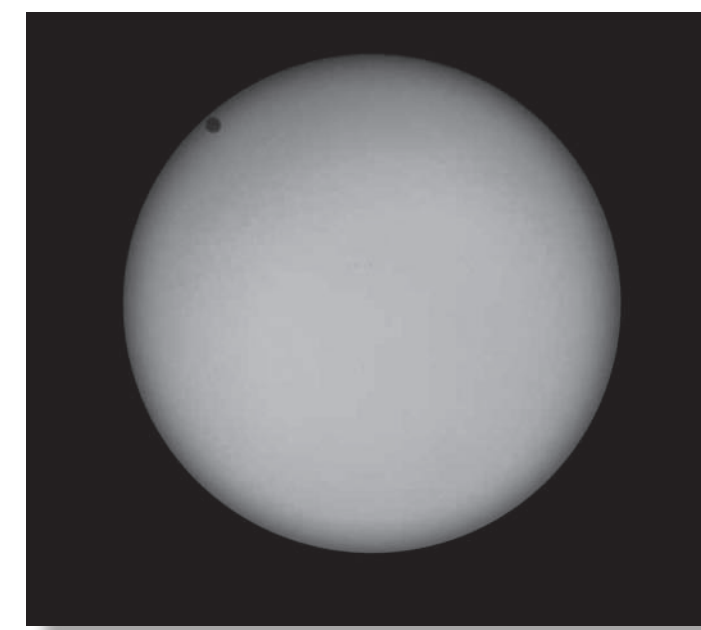


Photo by Becky Lowder: <http://www.transitsofvenus.com>

## B. Introducing Transits

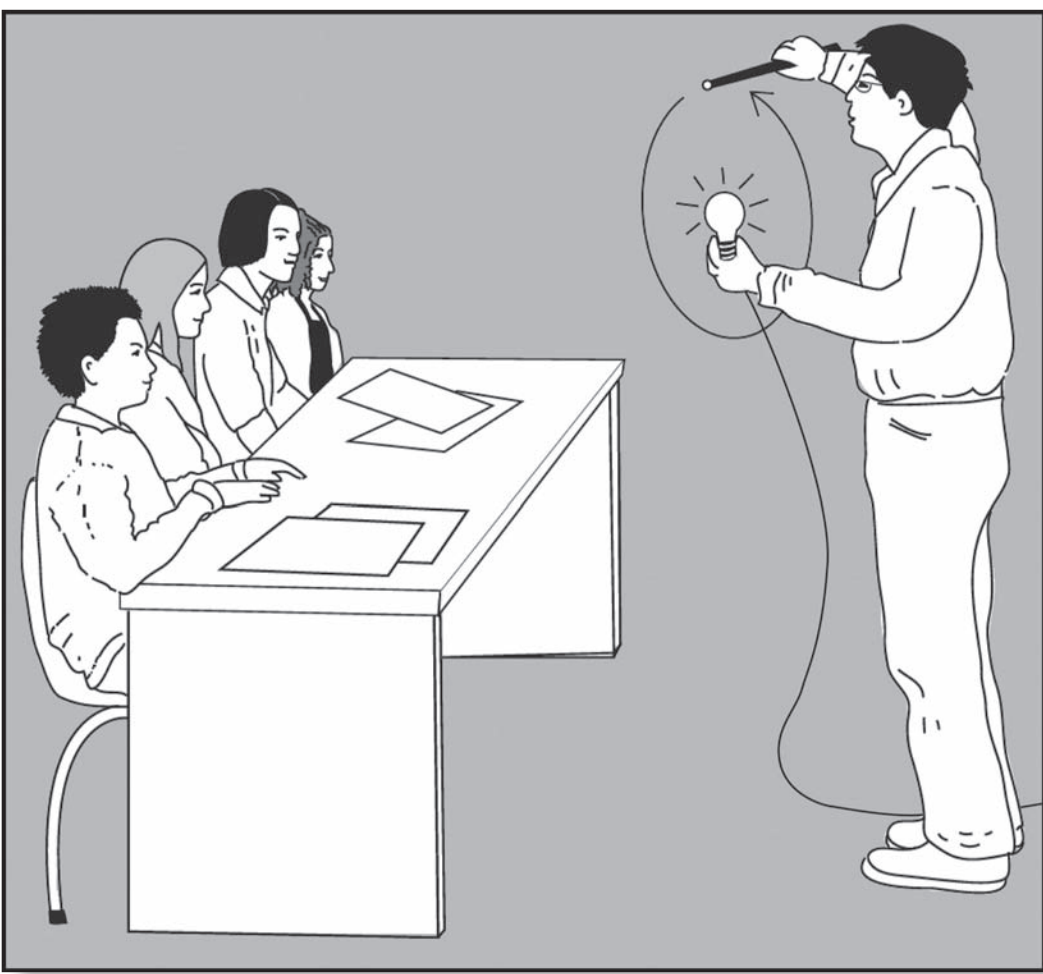
1. **Transit of Venus.** Show the image of the Sun with Venus in transit. Ask students to describe what they see. Confirm that the image is of our star, the Sun with the planet Venus passing in front of the Sun. Define a transit: when one object passes in front of another object.
2. **Extrasolar planet transits.** Ask "What will observers see if they watch a planet transit a star much more distant than the Sun?" Have them discuss the question in pairs, and then share their ideas. Explain that since other stars are so far away, it is very difficult for observers to see the disks of other stars, much less dark spots on the stars during transits. Instead, we see the star dim slightly for several hours as the planet passes in front of it.

## C. Making Transit Models

1. **Challenge teams to make Transit Models.** Organize the students in teams of 4 to 6 to construct models that demonstrate transits. Show them the materials available. The lamps/flashlights represent stars and beads or other materials represent planets. Explain that they will demonstrate their models to the rest of the class. Safety: If using 110V lamps, caution students: be careful about tripping over the power cords; do not touch a light bulb that has been on until it has cooled. Light bulbs get very hot quickly; nothing should be taped to the light bulb. Wear safety glasses to protect against broken light bulbs.
2. **Construct Models.** Give the teams 10-15 minutes to construct models. Circulate to check progress and safety. Encourage students to consider input from all team members in creating models. After 10-15 minutes, let teams know that

they should finish their models and plan their demonstration. Then have them all switch off the lamps.

3. **Demonstrate the Models.** Each team demonstrates and explains their model. Allow other students to critique the strengths and weaknesses of each model.
4. **Glare.** Students may notice that the glare from the light bulb makes it difficult to observe the models. If not, point this out and explain that the glare of the real stars is a major reason it is so difficult to observe the extrasolar planets.
5. **How Often Can We See Transits?** Darken the classroom, and switch on a lamp representing a star. Show students a bead attached to the end of a stick and tell them it represents a planet. Move the planet slowly around the star in a vertical orbit and have students raise their hands if they can see the planet pass in front of the star. Only a few students—those who are seated in "line of sight" with the plane of the planet's orbit—will raise their hands. Ask "What kind of orbit would allow almost everyone in the class to see a transit?" Under student direction, demonstrate the orbit, a horizontal one, with the planet passing between the star and the students. Even with this orbit, though, some students may not see the planet pass directly in front of the bulb. This illustrates that the likelihood of seeing a transit is low.



6. **Scale of the models.** Ask students to imagine that their models represent a extrasolar planet with an orbit about the diameter of Earth's orbit. (That's 150,000,000 km, or about 8 light minutes.) Remind students that the nearest stars in our

galaxy are several light years away, which is roughly a million times the orbit of the planet. In this scale model, then, the observer would be hundreds of kilometers away from the light bulb compared to the size of the extrasolar planet's orbit.

## D. The NASA Kepler Mission

Explain that the NASA *Kepler Mission* (launched in 2009) monitors more than 100,000 stars simultaneously, measuring changes in their brightness, and looking for sequences of transits. But because only a small fraction—less than 1%—of planets and stars will be lined up just right to detect transits, each planet found by this method represents about a hundred more extrasolar planets not found!

1. **Student Questions:** Discuss whether transit observations could answer any of the questions generated earlier.
  - **How large is the planet?** [The size of the planet determines the change in brightness of the star during a transit.]
  - **How long does it take for the planet to orbit its star?** [Measuring the time between transits tells us how long it takes the planet to orbit its star.]
  - **How far is it from its star?** [We can use Kepler's 3rd law to calculate the distance from the star to the planet. This assumes that the parent star is the same mass as the Sun.]
    - **What is it's temperature?** [With information about the type of parent star, and the distance from the star to the planet, we can calculate the temperature of the planet.]
    - **Is it in a planetary system with other planets?** [If more than one planet is making transits, they may be different size planets, and definitely have different orbital periods, just as in our solar system. The timing of transits and the changes of brightness during the observed transits provides this kind of information.]
    - **Is the planet Earth-like?** [By finding out how large the planet is, astronomers hope to find out whether planets the size of Earth are common, and how many of them are about the same distance from their stars as Earth is from the Sun.]
    - **Could the planet have liquid water?** [Liquid water could exist on the surface of an extrasolar planet if its distance from the star and the star's temperature are both just right.]

Download "Detecting Extrasolar Planets" and other activities at <http://kepler.nasa.gov/ed/activities>

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Page 5

## Human-Powered Orrery

An orrery is a mechanical model of the solar system that illustrates the relative motions and positions of bodies in the solar system. In this activity, you create a human-powered orrery that models the movements of the four inner planets.

## Get Ready! Materials and Preparation

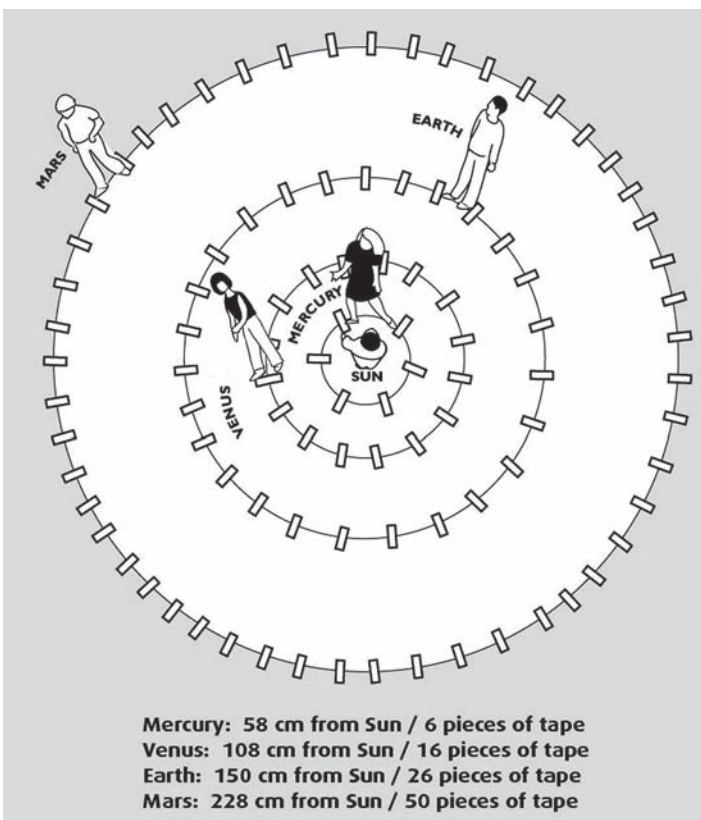
- A clear space at least 5 meters (about 17 feet) square
- A 2.5 meter piece of thin rope or string that does not stretch. Tie a large knot at one end of the rope and four more knots along the rope for the scale distance to each planet: 58cm (Mercury), 108cm (Venus), 150cm (Earth) and 228cm (Mars).
- Several rolls of masking or painter's tape (indoors) or chalk (outdoors)
- An overhead transparency of the outer planet's orbit, and 26 people are required for the orrery; if needed, recruit additional people.

## Go! Setting Up and Running the Orrery

1. **Define an Orrery:** Explain that an orrery is a scale model showing positions and motions of planets, and that the class will make a human powered orrery, one-hundred billionth the size of the actual solar system. The sizes of the planets' orbits are to scale, but the sizes of the planets and the Sun are not to scale. (Optional: Make scale models of Sun (13.9 mm), Mercury (0.05mm), Venus (0.12mm), Earth (0.13mm), Mars (0.07mm))
2. **Position the Sun:** Have students stand in a circle. In the center, mark an X with tape or chalk as the Sun's position. Ask a student to stand on the X.
3. **Mercury's Orbit.** Select 6 students to mark Mercury's orbit. Give each child a 10 cm piece of tape, and form a circle around the Sun. Show the knotted rope and explain that each knot on the rope is the scale distance of a planet from the Sun. With the Sun student holding the knot at the end of the rope over the central X, hold the first knot at 58 cm, pulling the string taut, and walk in a circle around the Sun. Have the 6 Mercury students space themselves evenly along the orbit and mark their positions with tape or chalk. Then, these students move off to the side.
4. **Model Mercury's Movement.** Have a student stand on one mark in Mercury's orbit. Explain that just as the model has a distance scale, it also has a time scale: each tape mark is about 2 Earth weeks. Have the Mercury student step from mark to mark around the Sun in a counterclockwise orbit. Ask "How many weeks does Mercury take to make a complete orbit around the Sun?" [12 Earth weeks.]
5. **Venus's Orbit.** Choose a different student to represent the Sun and have 16 students form a circle that is larger than Mercury's orbit. With the Sun student holding onto the knot at the end of the rope over the X, hold the second knot at 108

cm, and walk in a circle around the Sun. Ask the 16 Venus students to space themselves evenly along the orbital path and mark their positions with tape or chalk.

6. **Compare Mercury and Venus.** Ask the students to compare the orbits. [Venus's marks are closer together than Mercury's.] Choose two students to represent Mercury and Venus. Explain that both planets must move according to the same time scale—2-week steps. To synchronize movements, the class claps every "2 weeks." With each clap, Mercury and Venus move one step to the next mark, counterclockwise around the Sun. Start slowly, clapping about once every 2 seconds, then pick up the pace. After a dozen or so claps, stop and ask, "If Mercury and Venus were racing around the Sun, who do you think would win the race?" [Mercury.]
7. **Earth's Orbit.** Create the orbit of Earth like you did the orbit of Venus, using the 150 cm radius knot. Have 26 Earth students space themselves evenly on Earth's path, and mark their positions with tape or chalk. Point out that the marks on Earth's orbit are closer together than the marks in Venus's. Ask "Will Earth will move slower or faster than Venus?" [Slower.] Then, ask "Will Mars move slower or faster than Earth?" [Slower.]
8. **Mars's Orbit.** Create the orbit of Mars like you did the orbit of Earth, using the 228 cm radius knot. Have just 25 students space themselves evenly around the Sun and mark their positions with tape or chalk. Then, each student steps to a second position halfway between two marks, and places another mark; total is 50 marks.



Mercury: 58 cm from Sun / 6 pieces of tape  
Venus: 108 cm from Sun / 16 pieces of tape  
Earth: 150 cm from Sun / 26 pieces of tape  
Mars: 228 cm from Sun / 50 pieces of tape

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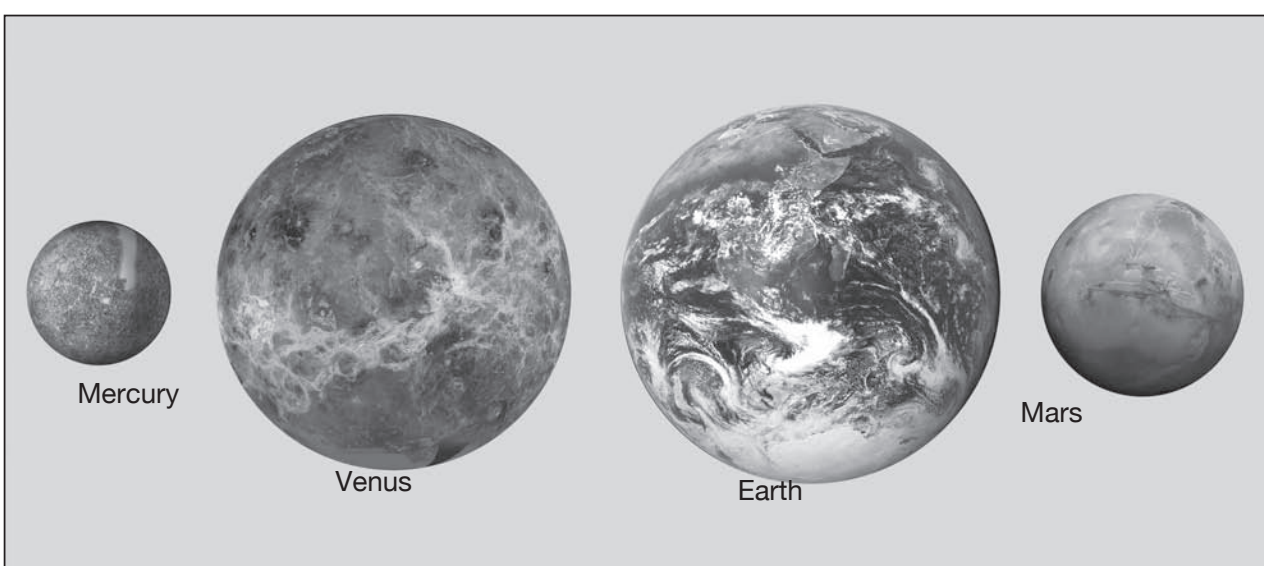
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Page 6



It is difficult to make the sizes of the planets to scale in this model. This illustration shows correct size scale.

9. **Run the Human Powered Orrery for all four planets.** Have 4 students line up as if they are about to begin a race, with one student on each planetary orbit. Tell the class that this is an unusual planetary alignment. Ask, "If the planets were racing to complete their orbits, which planet would you predict will win this race?" [Mercury.] Have everyone clap together chanting "2 weeks" with each clap. Stop after 26 claps when Earth has made one full orbit around the Sun. Ask the class how many weeks have passed. [52 weeks, or 1 year.] Ask students to describe the progress of the other planets and how much time has gone by for them. Re-run the orrery with different students to make sure that everyone participates. Solicit comments and observations from students as they observe the model in action.

## 10. What Does the Orrery Show Us?

Questions about planetary motion:

- a. "Is it the length of the planet's orbit, or the planet's speed that makes the difference in the time for one complete orbit?" [Both.]
- b. "What does the term 'year length' mean?" [Time for one complete orbit around the Sun.] "Which planet has the shortest year length?" [Mercury] "Which planet has the longest year length?" [Mars]
- c. "Is there a relationship between the distance from the Sun and their year lengths?" [The farther from the Sun, the longer the year length.] "Why do planets closer to the Sun have shorter year lengths?" [Shorter orbits and faster speeds.]
- d. "How would the movements of the planets appear to someone standing in the position of the Sun?" [The planets appear to move in an organized and orderly manner around the Sun. The viewer sees a consistent pattern in the motion of the planets.]
- e. "How do the movements of the planets appear to someone on the Earth?" [Since Earth is not in the center of the solar system and is in motion, the movements of the planets seem complex to an observer on Earth. The planets appear to wander about in different directions and speeds.] Explain that the word planet comes from an ancient Greek word that means "wanderer."

11. **How Good is the Model?** Conclude by having teams list the accuracies and inaccuracies of the orrery.

- Some things the model showed accurately:
  - All of the planets orbit the Sun in the same direction.
  - All of the planets' orbits are in the same plane.
  - The orbits are all close to circular.
  - The inner planets move faster and have shorter orbits than the outer planets.

- Some things the model showed inaccurately:
  - The sizes of the planets are not to scale.
  - The planets do not spin.

Optional: Have students make predictions about the year lengths and speeds of the outer planets. Then discuss this chart.

Planet	Earth Weeks	Earth Years	Orbital Speed (km/s)
Mercury	12	0.2	48
Venus	32	0.6	35
Earth	52	1	30
Mars	96	1.9	24
Jupiter	308	12	13
Saturn	766	29	10
Uranus	2,184	84	7
Neptune	4,290	165	5

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Page 7

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